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Operations Analysis (Study 2.6) Final Report

Volume IV

Computer Specification -- Logistics of Orbiting Vehicle Servicing (LOVES)

Prepared by ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

15 September 1973

Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2472

Systems Engineering Operations
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FOREWORD

The Logistics of Orbital Vehicle Servicing (LOVES) Computer Specification was developed as a part of Study 2.6, Operations Analysis. Under this study, a number of alternatives to improve utilization of the Space Shuttle and the Tug were investigated. Preliminary results have indicated that space servicing offers a potential for reducing future operational and program costs over ground refurbishment of Satellites. This specification defines a computer code which could be developed to simulate space servicing, and it is proposed that this computer code be a part of a follow-on to Study 2.6 during FY 1974.

This volume is one of four volumes comprising the final report for the FY 1973 effort on Study 2.6. The four volumes are:

Volume I	Executive Summary
Volume II	Analysis Results
Volume III	Payload Designs for Space Servicing
Volume IV	LOVES Computer Code Specification

Study 2.6 Operations Analysis is one of several study tasks conducted under NASA Contract NASW-2472 in FY 1973. The NASA Study Director was Mr. V. N. Huff, NASA Headquarters, Code MTE.

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FIGURES

TABLE

1. INTRODUCTION

Under Study 2.6, Operations Analysis, several alternatives were investigated to improve utilization of the Space Shuttle and the Tug upper stage. These included increased multiple payload deployment and retrieval operations, orbit plane change maneuvers, and other options. Results of these efforts led to consideration of space servicing as a means of improving Shuttle/Tug utilization.

The study also promoted a better appreciation for the Tug capabilities which should eventually result in a better utilization. For example, the space servicing approach reduces the weight carried to orbit to accomplish the mission and allows packaging in small increments which should certainly improve the loading of the Tug and Shuttle. Space servicing also strongly supports standardization of subsystems which can potentially reduce RDT&E and unit-recurring costs.

In order to analyze the concept of space servicing, it is first necessary to perform a statistical analysis of the failure characteristics of all payloads to be serviced. The large volume of space traffic projected for the time period of interest, the demands on the logistics fleet which must be integrated with other flight requirements, and the high degree of detail necessary to simulate space servicing all tend to favor a computer simulation as the appropriate study tool.

This computer simulation will treat a variety of payloads: expendable, retrievable, and serviceable. Traffic in the mission model is to be examined, and each spacecraft will be placed in one of the three groups. The computer program will simulate the placing of all spacecraft in orbit and the servicing or retrieval of spacecraft that have passed their useful life, depleted their expendables, suffered failures in critical components, or experienced degraded operation or reliability.

Ground operations will also be simulated. This includes decisions defining which items are to be loaded on each Tug and when each flight should be made. Scheduling to develop maximum utilization of available resources

is desirable in view of the limited supply of Tugs, Shuttles, and Space Replaceable Units (SRUs).

The computer program will be used to study such parameters as the number of launch vehicles required, the number of flights required, the outage time of various satellites, and the effects of various policies on these parameters as well as program costs. The simulation will treat each satellite vehicle and each launch vehicle as a discrete element. The satellite vehicles will be subdivided into a number of space replaceable units to be serviced on-orbit.

The program will be written to allow a substantial variation in the input parameters, including the policies which determine when launches are actually made. Several forms of output from the computer program will be available. This output will be selectable and includes the ability to trace the history of a particular satellite as well as the ability to ascertain such summary statistics as number of launches, number of modules used, etc.

The program is to be written for the CDC 7600 and to be compatible with the NASA CDC 3200 (32-bit word length) and the UNIVAC 1108 computing systems. The program shall be designed for interactive operation from a remote terminal. Supporting documentation will be generated.

The program will have the capability to accept various logistic vehicle definitions such that tradeoffs of operational costs can be performed. The vehicles will be described in terms of performance, mission time, and availability. The types of vehicles to be considered for servicing missions are the Shuttle, Tug, and Solar Electric Propulsion Stages (SEPS) and various combinations (i. e., Tandem Tugs). Servicing missions shall include low altitude and geosynchronous orbits and certain multiple orbit operations.

The East Coast and West Coast launch facilities will be treated in this simulation by making separate runs for each. This gives valid results provided the Shuttles and Tugs are not interchanged between the two launch sites. The Department of Defense space traffic may be treated as a set of scheduled

launches of fixed mission duration. This imposes certain constraints on vehicle availability which must be recognized when assessing NASA missions. A single fleet will service both NASA and DOD operations although joint operations will not be performed. The simulation will test various fleet sizes and servicing policies, give cost comparisons, and test sensitivities of ground rules and input data. The output of the computer program will contain data on distribution of flights, availability of operational systems, loading efficiency, costs, etc.

2. SUMMARY DESCRIPTION OF COMPUTER SUBROUTINES AND THEIR INTERACTION

This section introduces some suggested portions of the computer program and defines their interaction. Detailed descriptions may be found in Section 5. Refer to Fig 1 for a graphic presentation of the interactions.

A. DATA INPUT SUBROUTINE

This subroutine is designed to ascertain from the user necessary data to define completely the problem. These inputs are detailed in the next section of the report. This subroutine communicates with most of the remaining subroutines by supplying inputs to these subroutines. These inputs define satellite and launch vehicle parameters, policies that are available, and desired output.

B. MODULE FAILURE AND WARNING SUBROUTINE

This subroutine will generate failure times and warning times for each SRU through the use of a random number process. Warning times are those times, generally preceeding SRU failure, when some indication is received from the SRU that a non-critical component has failed. Another type of indication is available by monitoring depletion of expendables. The program will accommodate active and dormant failure rates. The principal use of the outputs of this subroutine is to assist in defining the system status; that is, whether various satellites are operative.

C. CURRENT SATELLITE SYSTEM STATUS SUBROUTINE

This subroutine will contain the status of all satellites and each constituent SRU. This subroutine will also have the capability to monitor the availability of multi-satellite systems; that is, the state of each individual satellite within that system. The principal inputs to this subroutine will be initialization from the input subroutine and data relating to failed modules. In addition, information will come to this subroutine after the satellites have been serviced containing a new birth of time for that module. The

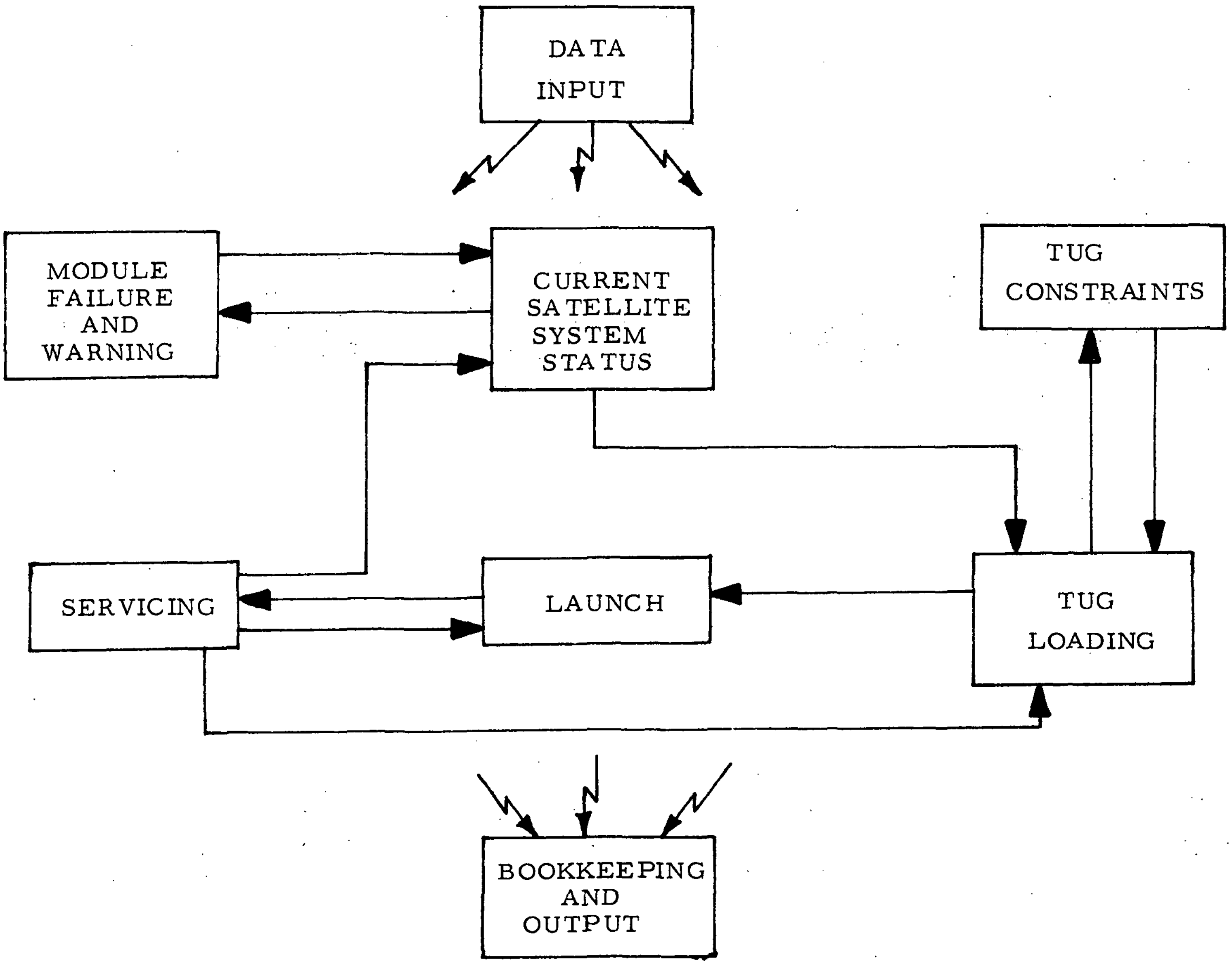

Figure 1. Simplified System Flow Diagram

principal outputs from this subroutine will be to the Bookkeeping and Output Subroutine and the Tug Loading Subroutine.

D. TUG CONSTRAINTS SUBROUTINE

The Tug Constraints Subroutine calculates information relative to various constraints that determine how many modules and which types can be loaded on the Tug. In particular, constraints to be considered are the volume of the modules and the ΔV capability available to visit more than one satellite on a flight. Inputs to this subroutine are program inputs and the status of and requests from the Tug Loading Subroutine. The principal output to the Loading Subrouting delimits the loading possibilities.

E. TUG LOADING SUBROUTINE

Given that a number of modules have failed or have had warnings occur, the question becomes: how and when shall these modules be loaded? On which Tug shall they be loaded and in what order, and which satellites shall be visited by which Tug? The limitations imposed by the Tug constraints will determine in some cases which modules can be serviced on a particular flight. A number of loading possibilities exist and will be available at the user's option. For example, the Tug can be loaded with failed modules as the failures occur, with modules that have had warnings, or with only a single module if that module is important enough. In addition, scheduled flights, those which are not caused by failures or warnings, will also have to be integrated into the loading routine. The possibility of a Tug flight containing both satellites to be deployed as well as replacement modules for satellites in orbit will be considered. The program shall have the capability to indicate that specific payloads will be launched and/or retrieved using a tandem Tug.

This subroutine will also consider limitations on the number of modules available on the ground. The pipeline of any particular supply of modules available is finite, and if no modules are available, it will not be possible to satisfy the failed satellite. It will then be necessary to wait

until a module becomes available as a result of either being manufactured or refurbished (after having been brought down from another satellite). The principal outputs of this subroutine are to the Launch Subroutine.

F. LAUNCH SUBROUTINE

In this subroutine, the launches of the loaded Tugs are queued up, and the order and timing of the launches are established according to the policies which form inputs to this subroutine. Constraints on the launch vehicles (established principally by the orbits of the satellites) as well as any other operational questions may enter into the policies. The principal outputs of this subroutine are to the Servicing Subroutine.

G. SERVICING SUBROUTINE

This subroutine takes the information from the Launch Subroutine, pertaining to modules and satellites that have been put into orbit and causes changes in the status of the modules and satellites in the Current Satellite System Status Subroutine. The servicing subsystem also changes the status of the Shuttle and Tug queues by returning vehicles to the queues following the flight. The principal outputs of this subroutine are to the Current Satellite System Status, Launch, and Tug Loading Subroutines.

H. BOOKKEEPING AND OUTPUT SUBROUTINE

Data from other sections of the program are centralized, assembled, and summarized in this subroutine. The subroutine should have the option of providing a number of degrees of detail so that users with different requirements can obtain the amount of detail they desire. This subroutine will also combine the statistical outputs with costing routines to provide costing data.

3. COMPUTER PROGRAM INPUT DATA

This section delineates the input data required for the initiation and operation of the computer program. Reliability data is treated in the form of a Weibull distribution and its parameters, alpha and beta. The Weibull distribution takes the form of: Reliability $(t) = e^{-(t/\alpha)^{\beta}}$. The program should be written such that changes in data from one run to the next can be made without requiring that all data be input a second time.

A. <u>TOTAL TIME TO BE SIMULATED (≤20 years)</u>

B. <u>INPUT DATA FOR EACH SATELLITE (≤999 satellites)</u>

1. List of modules (SRUs) comprising the satellite and for each module, the time the module is born, the warning time, and the failure time of the module
2. Identification of the non-replaceable unit and its birth and failure time
3. Total weight of the satellite ≤29,500 kg (≤65,000 lb)
4. Total volume of the satellite ≤311.52 m^3 (≤11,000 ft^3)
5. Priority assigned to the satellite (yes or no)
6. Number of satellites which comprise this satellite system (≤16)
7. Description of the orbit for the satellite (≤99 possibilities)
8. Complete schedule of launches, retrievals, and mission equipment changes for the satellite (total ≤ 40)
9. Program termination time for the satellite (≤20 years).

C. <u>FOR EACH SATELLITE SYSTEM</u>

1. Delineation of all satellites in this satellite system (≤16)
2. Criterion for operational system (e.g., 3 out of 4).

D. <u>FOR EACH MODULE TYPE (≤999 Types)</u>

1. The failure parameters* α_f, β_f, and tt_f ($\alpha \leq 999, \beta \leq 9$, $tt \leq 20$) **

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* tt_f is the truncation time on the reliability function.

** Similar values may be used for the dormant failure parameters.

2. The warning parameters α_w, β_w, and tt_w (same as above)
3. Weight of the module $\leq$ 453.55 kg ($\leq$999 lb)
4. Volume of the module $\leq 28.29 m^3$ ($\leq 999\ ft^3$)
5. Number of modules in the pipeline and availability date for each ($\leq$99)
6. Time to repair a failed module ($\leq$1 year)

E. SHUTTLE

1. Number of Shuttles available for Tug flights ($\leq$3)
2. Turn-around time after return of Shuttle ($\leq$0.5 year)
3. Launch delay ($\leq$0.5 year)
4. Minimum time between Shuttle launches ($\leq$0.5 year)
5. Probability of successful launch.

F. TUG ($\leq$9 Versions Including Multiple Stage Options)

1. Number of Tugs available ($\leq$9)
2. Turn-around time after each flight ($\leq$0.5 years)
3. Volume capacity $\leq 311.52 m^3$ ($\leq 11,000\ ft^3$)
4. Number of modules capacity ($\leq$99)
5. Weight of service equipment $\leq$453.55 kg ($\leq$999 lb)
6. Information on payload - ΔV tradeoff (to be specified later)
7. Specification of whether Tug is recoverable or expendable
8. Criteria for launch of partially filled Tug ($\leq$9)
9. Maximum wait before launch ($\leq$1 year).

G. POLICIES

1. LOADING POLICIES
   a. Load Tug when sufficient modules have been identified as failed modules
   b. Load Tug when a single module has failed; complete Tug loading with warnings
   c. Load Tug with warnings when enough have occurred

d. Priority loading; for example, load all of one type of module

e. Load Tug after some maximum waiting time measured from time first SRU or satellite is available for loading on Tug

2. LAUNCH POLICIES

a. Launch chronologically (according to time Tug has been filled) following some specified delay

b. Launch Tug loaded with priority satellite in precedence over other Tugs (following some specified delay).

3. VARIOUS COMBINATIONS OF THE ABOVE

4. POLICIES FOR TUG LOADING AND LAUNCHES

This section describes policies that determine which SRUs and satellites are loaded on which Tugs and when launches of the combined Shuttle/Tug system are made. A number of policies are under consideration for actual use and to the extent possible, the program should have the flexibility to include other policies similar to those presented here.

A. POLICIES FOR TUG LOADING

The first policy for loading the Tug is to fill the Tug to (a minimum of some fraction of) its total payload weight and volume constraints with failed modules. In this policy, only failed modules would be considered in the Tug Loading Subroutine, and the launch would take place when the subroutine had determined that a particular load was at least a given fraction (which would be a program input) of the Tug payload for that orbit and that number of satellites visited.

A second Tug loading policy is to initiate a launch after any failure of a module and to fill the remaining capability of the Tug with modules that have had warnings. This is done by examining the Current System Status Subroutine for all modules that have had warnings and by choosing those that have had the longest time since warning. The number of modules to be chosen would be the largest number that have had warnings that could be accommodated on that flight after the failed module has been loaded. In this policy, a flight would be made each time a module failed.

A third policy would fill (to some minimum fraction) the Tug with modules that have had warnings. Launches could occur in the absence of any failures. When a Tug was filled, it would be launched. If a failure occurred before the Tug was filled, the flight would be made with that failure and the warnings that had occurred prior to the failure.

If a module is a priority module (which may mean that it is any module from a priority satellite or is a particularly critical module for a

non-priority satellite), it enters after some change in state (warning or failure) at the head of the queue of modules to be loaded on the Tug and committed to the appropriate orbit. If necessary, other modules will be off-loaded from that Tug. If the Tug is not filled when the priority module is included, additional modules will be chosen from the warning modules with the longest warning being loaded first. In this policy, the loaded Tug would then be immediately transferred to the Launch Subroutine so that launch could take place in an expeditious manner.

In order to maintain a minimum level of service, it will be desirable to guarantee that no SRU or satellite is required to wait longer than a specified time before its Tug is moved to the launch queue.

B. POLICIES FOR LAUNCH

The first policy for launch involves launching the Tug in the order in which it arrives in the Launch Subroutine. Tugs come to the Launch Subroutine, are queued up, and launches are made in a first-in, first-out manner. This same method would be used for Shuttle launches where Tugs are not employed.

Priority Tugs can be moved to the head of the queue of Tugs, or more exactly, ahead of all non-priority Tugs but at the end of any queue of priority Tugs.

5. DEFINITION OF SUBROUTINES

This section contains the detailed descriptions of the subroutines. Each detailed description is keyed to one or more system flow diagrams, and each block of each diagram contains a number which identifies that block and which is referred to in the text. Blocks representing input data from other subroutines are identified by enclosing that block in dashed lines. Blocks representing output data from the subroutine under consideration to other subroutines are represented by double-scoring the blocks.

Descriptions given in this section often refer to the various subroutines by the initials of the names of the subroutines. For the convenience of the reader, these abbreviations are summarized here:

INSR	Data Input Subroutine
MFWSR	Module Failure and Warning Subroutine
CSSSSR	Current Satellite System Status Subroutine
TCSR	Tug Constraints Subroutine
TLSR	Tug Loading Subroutine
LSR	Launch Subroutine
SSR	Servicing Subroutine
OUTSR	Bookkeeping and Output Subroutine

There may be a number of ways to control the overall program timing available to the computer programmer. One is suggested here, although it is not necessarily meant to be the one chosen. Referring to Figure 1, it can be seen that the program may be divided into a number of separate subroutines. Among these subroutines, the ones that have events occur that may represent elapsed time are Current Satellite System Status Subroutine, Tug Loading Subroutine, Launch Subroutine, and the Servicing Subroutine. Events may occur following delays at various points within these subroutines.

It is suggested that within the Bookkeeping and Output Subroutine, an Executive Timing Section be maintained to control events so that they

occur in the proper chronological order. This Executive Timing Section would take inputs from each of the four subroutines describing when the next action in that subroutine was scheduled to occur and would keep the chronological ordering of the events consistent among the four subroutines. Action involving the Tug Constraints and Module Failure and Warning Subroutines does not involve elapsed time and need not be considered by the Executive Timing Section.

A. DATA INPUT SUBROUTINE

The purpose of the Data Input Subroutine is to take data from the program user describing the system to be simulated and to convert it to a format appropriate for other subroutines in the program and to direct the data to the appropriate subroutine. The Data Input Subroutine will also specify which outputs are required and which of the policy options previously delineated will be applied to the particular simulation.

This subroutine will also initiate certain portions of the program at the start. For example, it will call for the generation of warning and failure times for all SRUs on orbit at the start of the simulation.

As much as possible, the Data Input Subroutine should allow for flexibility. In particular, it should not be necessary to repeat data that does not change from one run to the next. The Data Input Subroutine should have the capability to accept data from a remote terminal.

The exact form of this subroutine is dependent upon the computer language used. The listing of data to be supplied in this subroutine was given in Section 3 together with the limits to be expected for the data. The indication of which subroutines will use this data is given in the descriptions of these subroutines in subsequent parts of this section.

B. MODULE FAILURE AND WARNING SUBROUTINE

This subroutine is characterized by a particularly non-complex interface with the other subroutines (Refer to Figure 2). A request for a failure time and a warning time for a particular SRU is generated in the

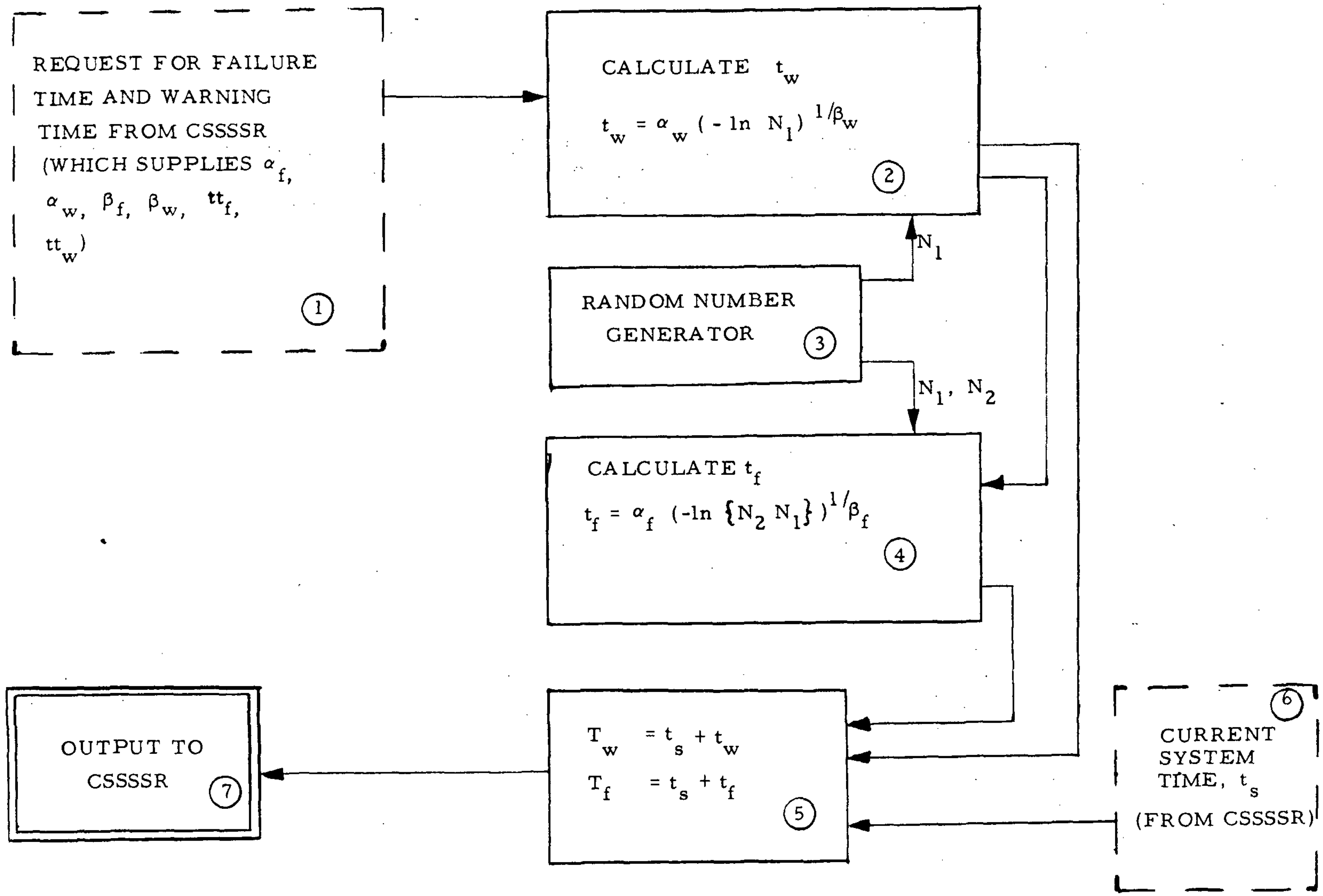

Figure 2. System Flow Diagram, Module Failure And Warning Subroutine

Current Satellite System Status Subroutine and sent to the Module Failure and Warning Subroutine. This is represented in Figure 2 by (1). Note that when the request for data is sent from CSSSSR, it must include the values for alpha, beta, and truncation time for both warning and failure functions.

The flow of activity then generates the warning time t_w according to the equation given in (2). In order to calculate this, a random number denoted by N1 is generated in the random number generator (3). The numbers from this random number generator are uniformly distributed between zero and one.

After the warning time t_w has been calculated, the next step calculates the failure time t_f. This is done in (4) using random number inputs from the random number generator. The inputs are N1, the same number used in (2), and also N2. A new pair of random numbers N1 and N2 is generated for each request of a t_w and t_f. The outputs from (2) and (4) are inputs to (5) which corrects the calculated warning and failure times by adding the current system time (6) to those values so that the future warning and failure times reflect the correct starting time. The outputs from (5) go to CSSSSR (7).

C. CURRENT SATELLITE SYSTEM STATUS SUBROUTINE

The data identifying satellite and SRU parameters as well as their current status; e.g., time of next failure of each satellite in the simulation, are stored in this subroutine. This subroutine also contains the clocking mechanism for the simulation.

The data on each satellite can be divided into three portions (Refer to Figure 3). There are the fixed data on the satellite (1); e.g., time the satellite was born, the orbital parameters, and the priority assigned to the satellite. A second set of data for the satellite is the fixed data for each SRU (2); e.g., alpha, beta, and weight. A third set of data (3) for the satellite is the variable data for each SRU; in particular, the time that each SRU was born, will have a warning, and will fail. A complete list of data for these three portions is given in Table 1. The data comes from the Input

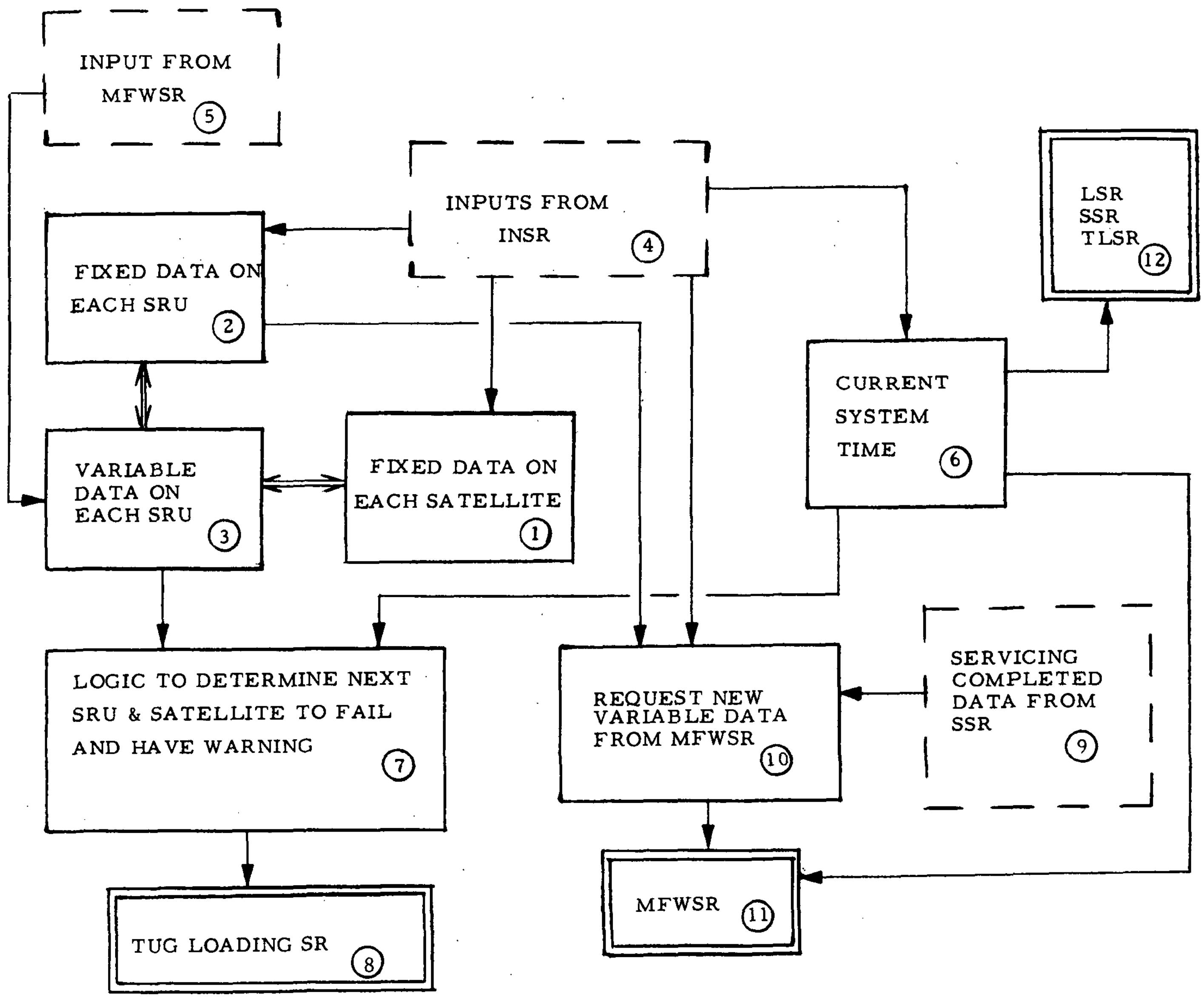

Figure 3. System Flow Diagram, Current Satellite System Status Subroutine

Table 1. Satellite Data

SATELLITE FIXED DATA

1. List of SRUs comprising the satellite.
2. Identification of the non-replaceable unit.
3. Total weight of the satellite.
4. Total volume of the satellite.
5. Priority assigned to the satellite.
6. Identification of other satellites which comprise this satellite system.
7. Description of the orbit for the satellite.
8. Complete schedule of launches, retrievals and mission equipment changes.
9. Program termination time.

SRU FIXED DATA

1. The failure parameters, α_f, β_f, and tt_f.
2. The warning parameters, α_w, β_w, and tt_w.
3. Weight of the module.
4. Volume of the module.
5. Number of modules in the pipeline and availability for each.
6. Time to repair a failed module.

SRU VARIABLE DATA

1. Birth time.
2. Warning time.
3. Failure time.

Subroutine (4) in the cases of the fixed data and from the Module Failure and Warning Subroutine (5) in the case of the variable data.

Data from (3) and also from the Current System Time (6) are used in (7) to determine the next SRU failure times and the warning times for each SRU. This could be done, for example, by ranking the failure times of all the SRUs in the system chronologically and stepping through the list until the first failure time is reached. At this point, data on that failure are sent to the Tug Loading Subroutine (8).

Data in the Current Satellite Systems Status Subroutine are updated when a request comes from the Servicing Subroutine (9). This goes to (10) which now also will have received a request for data from (4) at the beginning of the program. In order to generate this data, information is received from (2) on the alphas, betas, and truncation times. These requests are sent to MFWSR (11).

The Current Satellite System time is also sent to several other subroutines (11), (12).

D. TUG LOADING SUBROUTINE

This subroutine takes data pertaining to failed modules and scheduled flights and combines it with the constraints put upon the operation of the Tug to appropriately load the Tug and transfer it to the Launch Subroutine where it is combined with the Shuttle and launched. In this subroutine the word "Tug" is used in a generic sense and may refer to any of the several verisions of upper stages. If two or more Tugs are available in a single simulation run, the program will choose the appropriate one. However, criteria for the selection must be provided in such a case.

Information that a failed module is available for loading comes from CSSSSR (1) (Refer to Figure 4). It is first necessary to determine if there is a replacement SRU in the inventory pipeline of SRUs (2). This is done by consulting the pipeline queue (3) which in turn is replenished by refurbished modules. Those data come from the Servicing Subroutine (4).

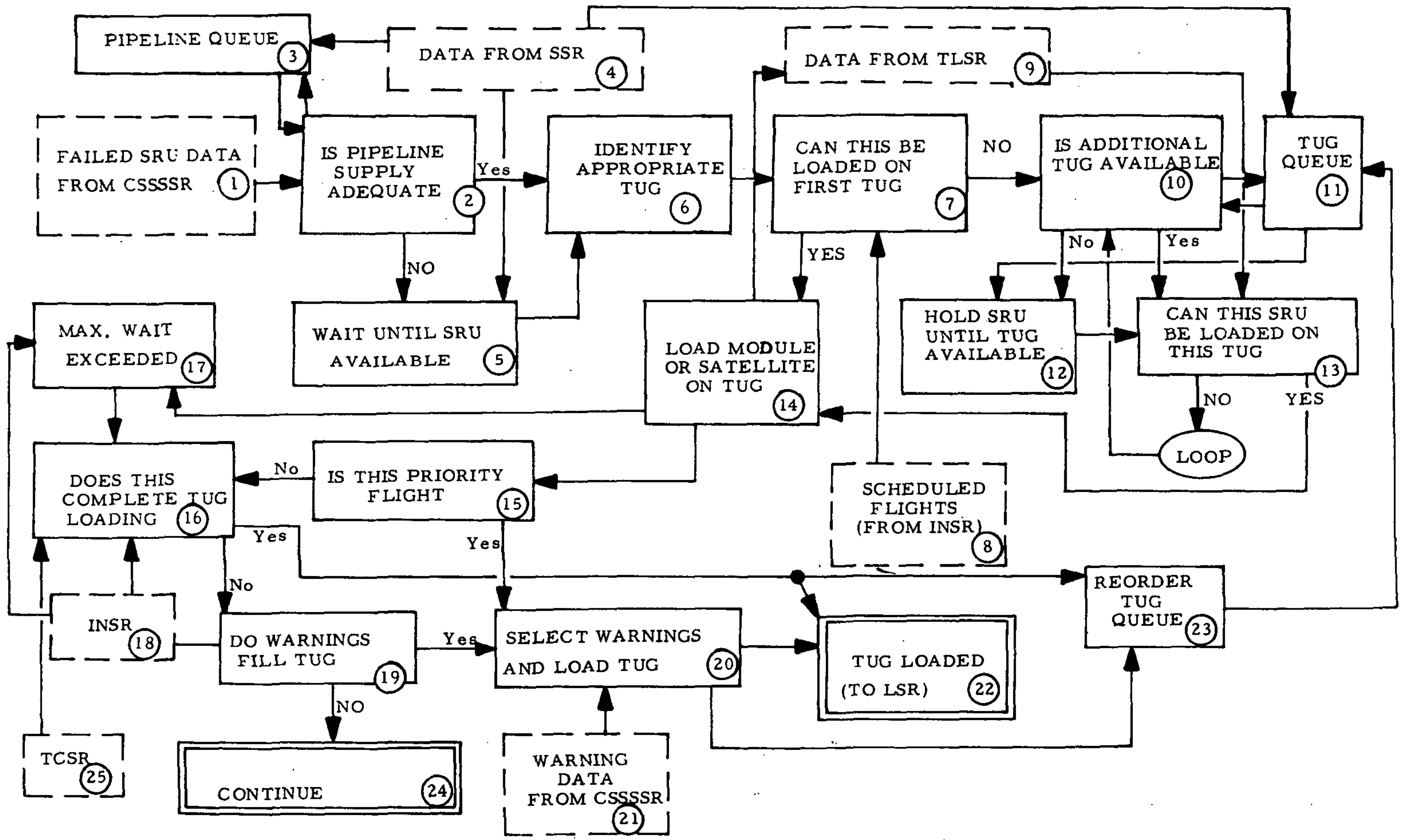

Figure 4. System Flow Diagram, Tug Loading Subroutine

If the pipeline supply is not adequate, the data pertaining to the failed module are held in (5) until information from (4) indicates that a refurbished module is available. When the pipeline supply is adequate, either as a result of (2) or (5), the appropriate Tug is identified (6).

It is assumed that since the SRU is part of a particular satellite and since Tugs service particular satellites, this SRU can uniquely be identified with the particular Tug. We determine if this SRU can be loaded on the first available Tug suitable for its orbit (7). It should also be noted that the same question is asked of all scheduled flights (8) which are assumed to enter (7) according to their chronological time of birth.

If the SRU or satellite cannot be loaded on the first Tug, which can be determined by consulting the Tug Constraints Subroutine (9), then it is appropriate to ask if any other Tug is available for this module to be loaded on (10). This can be determined by examining the queue of Tugs (11) to see if any are available. If there are no additional Tugs available (12), it is necessary to wait until information from the Tug queue (11) indicates that a Tug is available. When this happens or if the Tug was available earlier (when the decision was made in (10)), it must be ascertained if SRU can be loaded on this second Tug (13). If the answer is negative, the program loops looking again for additional Tugs until it either runs out of Tugs or finds one where the SRU or satellite, as the case may be, can be loaded. If the answer is positive (it can be loaded on the Tug), the activity moves to (14) loading the module or satellite on the Tug. The activity also moves to (14) if the answer to (7) was positive. At this point, the information on modules loaded on this Tug in TCSR is updated to add the new module.

After the module is loaded on the Tug, it is appropriate to determine if this is a priority flight (15). If it is not a priority flight, then it must be determined if this module completes the loading of the Tug (16). This question requires an input from TCSR (25) identifying how many modules are loaded, what fraction of the volume is filled, and how much payload remains. If any of these exceed the limits from INSR (18), the loading is complete. At this point, it is possible to determine if the loading of expend-

ables for satellites now scheduled for servicing would complete the loading. Thus, a certain level of depletion would qualify SRUs with expendables for a space-available-basis replacement. One additional input to (16) concerns the maximum waiting time (17). In the event that a module has waited on a Tug more than a certain amount of time, the Tug is moved to the launch area. The inputs to (17) come from (14), the time the first module was loaded on the Tug, and from the Input Subroutine (18) which identifies how long a wait is allowed. If the answer to (16), does this complete Tug loading, is negative, a question of policy is asked. This question is: given that we have a reason to fill one part of the Tug, should the remaining part of the Tug be filled with warnings (10)? The answer to this question comes from the Input Subroutine (18). If the answer is negative, the program continues waiting for the next event (24).

If the answer to the question concerning priority flights (15) or the Tug being filled with warnings (19) is positive, it is necessary to select the warnings and load the Tug (20). The warnings may be selected by choosing those with the longest waiting time; that is, those where the warnings occurred first. These data on warnings come from CSSSSR (21).

The activity from (20) or from a positive answer to the question in (16) results in the complete loading of the Tug and the transfer of this Tug to the launch subroutine so that it can be mated with the Shuttle and launched (22). This action also leads to a reordering of the Tug queue (23) so the Tug that has just been transferred to the Launch Subroutine is taken out of the queue, and the position of the remaining Tug is moved up to fill the empty spot left by the transferred Tug.

E. TUG CONSTRAINTS SUBROUTINE

It is not always possible to load a module on a Tug as soon as one has failed and a new module has been found to take its place. Rather in some cases, the payload and velocity limitations on the Tug will dictate that the module wait for a subsequent flight. Other types of contraints, in addition to the payload ΔV constraint, may also eliminate a module from a particular

Tug loading. This subroutine will determine whether a module can be loaded on a particular Tug.

Information describing the candidate module and the Tug to be considered for carrying that module arrives from the Tug Loading Subroutine (1) (Refer to Figure 5). The subroutine first determines if the modules exceed the constraint on the volume of the modules that can be loaded on the Tug (2). To do this, it is necessary to consult the inventory of items already loaded on that Tug (3). This might be stored as a table in (3). Information for constructing the table comes from the Tug Loading Subroutine (4) and is sent to the Tug Constraint Subroutine when the module is actually loaded. If the volume constraint has not been exceeded, we next determine if the payload ΔV constraint has been exceeded (5). This will be done in a separate portion of the program (6) to be specified elsewhere. If the payload ΔV constraint has not been exceeded, the output of this subroutine to the Tug Loading Subroutine is to indicate that the constraint is not exceeded and that the module may be loaded on the Tug (7). If the answer in (2) or (5) was positive, the output is that this constraint has been exceeded and this module cannot be loaded on this Tug (8).

F. LAUNCH SUBROUTINE

In this subroutine, the Tug has been filled to a satisfactory limit, is joined with the first stage, and launched. Tugs going to different orbits may be queued up at one time waiting for an available Shuttle.

Information that a loaded Tug has been created comes from the Tug Loading Subroutine (1)(Refer to Figure 6). The first consideration is whether or not a Shuttle is available to be mated with a Tug (2). This can be determined by consulting the Shuttle queue (3) which is updated by the Servicing Subroutine (4). If the Shuttle is not available, it is appropriate to determine if this Tug is a priority Tug; i.e., does it contain a priority satellite (5). If this answer is positive, then this Tug is moved ahead of non-priority Tugs waiting for an available Shuttle. Information on the availability of the Shuttle comes from (3).

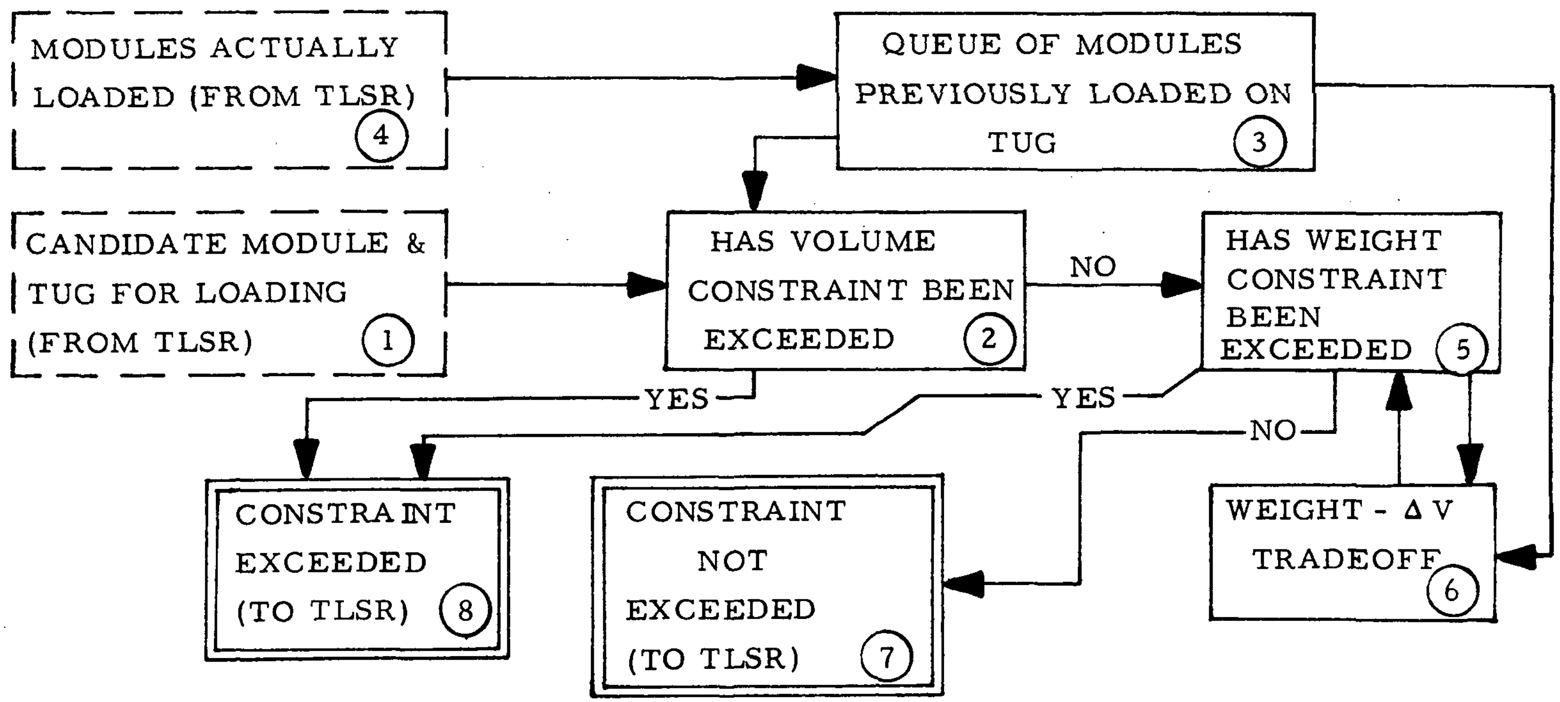

Figure 5. System Flow Diagram, Tug Constraints Subroutine

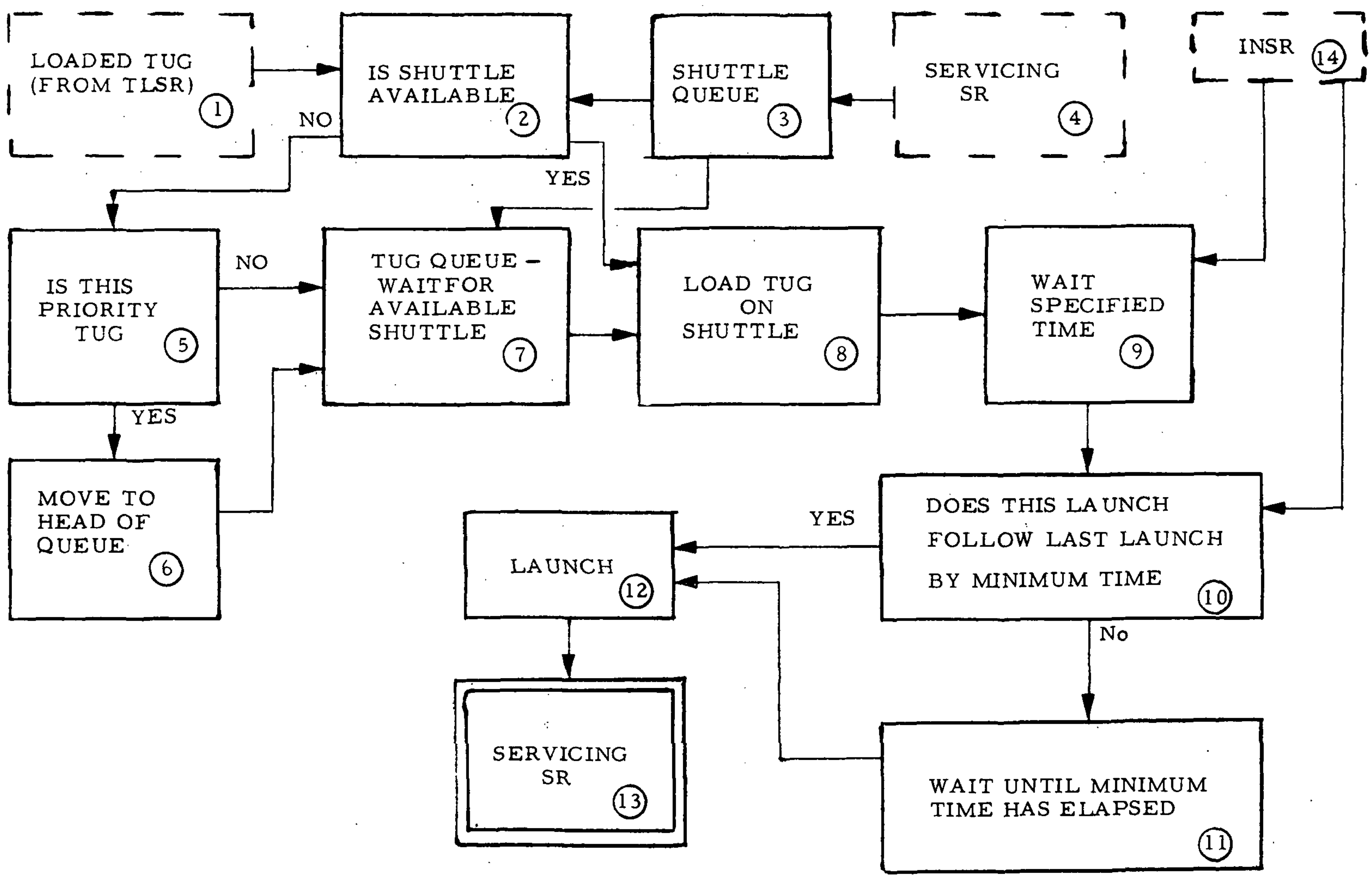

Figure 6. System Flow Diagram, Launch Subroutine

If the answer to (2) was positive or after the Tug has waited for a Shuttle, the activity moves to (8) which represents the Tug being loaded on the Shuttle. After a specified time from INSR (14) has elapsed (9), the Shuttle can be launched provided it does not follow too closely the last launch (10). The assumption here is that two Shuttles cannot be launched arbitrarily close together. If the launch does not follow the last launch by the minimum time required (11), the Shuttle waits until that minimum time has elapsed and then the launch occurs (12). Information that this has occurred is then sent to the Servicing Subroutine (13).

G. SERVICING SUBROUTINE

This subroutine models the actual servicing or changing of the status of satellites in the program. It causes new birth times and death times to be generated for satellites via the Current Satellite System Status Subroutine. It also returns Tugs and Shuttles to availability queues.

The Launch Subroutine indicates that a launch has taken place (1) (Refer to Figure 7). The success of the launch is determined first (2), based on an input probability of successful launch (3) and a random number (4). If the launch is not successful, all items are returned to queues to wait for future launches (5). If the launch is successful, the first satellite position is then visited (6). At this point, the servicing of that satellite is accomplished (7), and replaced modules from that satellite reenter the pipeline with a new date when they will become available (8). This date reflects the sum of current system time (9) and a period for refurbishment.

After the first satellite position has been serviced, the subroutine determines if this is the final satellite position to be serviced this flight (10). If the answer is no, the subroutine visits the next satellite position. This looping is repeated until the answer to (10) is affirmative. The Shuttle is then assumed to be returning to earth, and it is necessary to determine which Tug, if any, it will carry. If the Shuttle carries the same Tug down that it carried up (11), all items can be returned to queues (12). If the Shuttle did deploy a Tug (13), that Tug is placed in a queue for Tugs holding

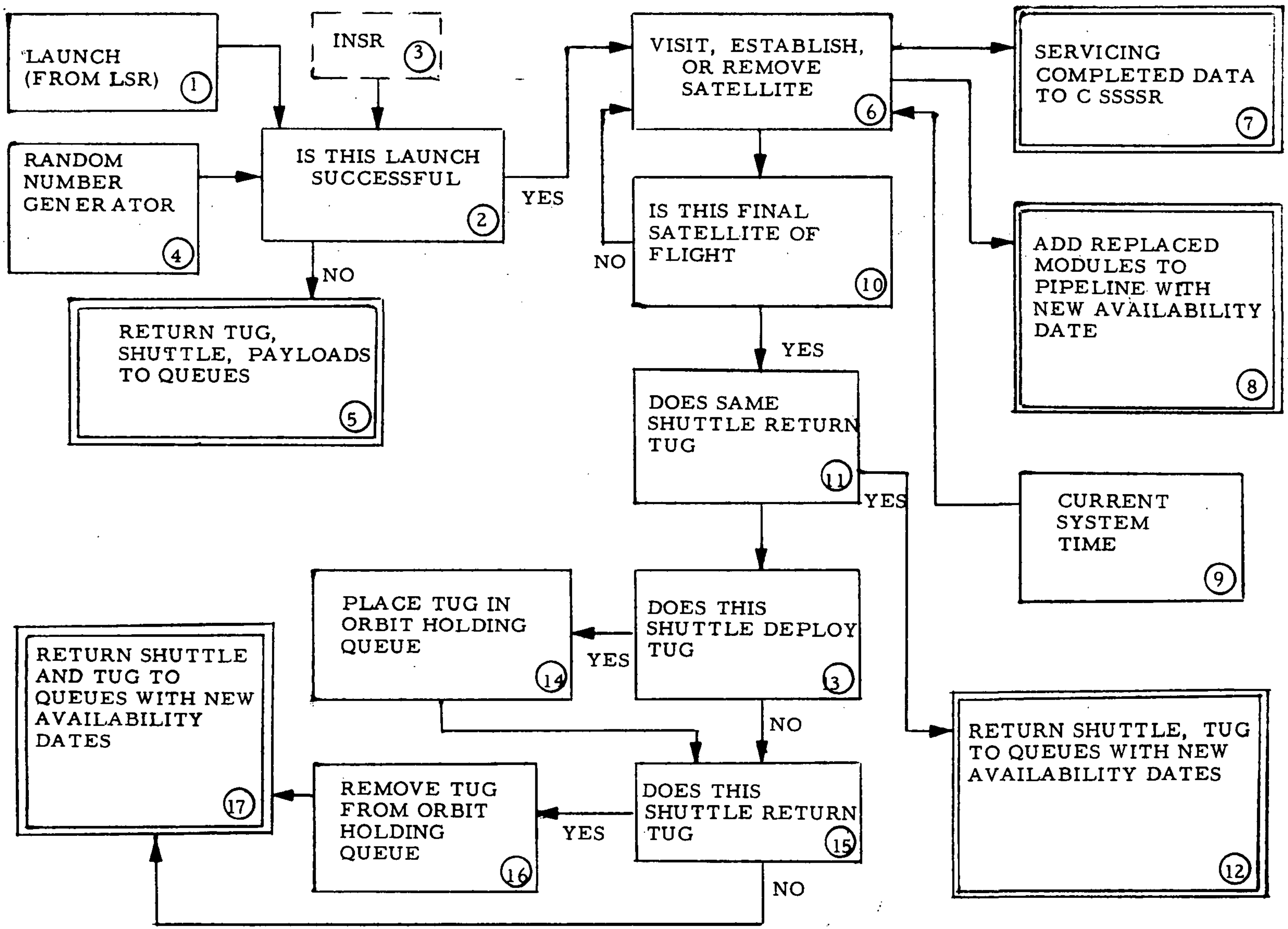

Figure 7. System Flow Diagram, Servicing Subroutine

on-orbit waiting to be returned (14). If the Shuttle is to return a Tug to earth (15), the Tug is removed from the holding queue (16). At this point, the Tug and Shuttle are returned to their respective queues, assigned new availability dates, and the service flight is terminated (17).

H. BOOKKEEPING AND OUTPUT SUBROUTINE

Data from other subroutines will be collected and summarized in the Bookkeeping and Output Subroutine. The operation of this subroutine will be specified by the program user who will indicate the level of detail desired as well as specific outputs he wishes to receive. This subroutine will combine the statistical outputs with costing routines to provide costing data. The flexibility to allow different costing approaches will be maintained. The detailed list of possible outputs is contained in Section 6.

The system flow diagrams given in earlier subsections do not in general indicate where data must be taken for the Bookkeeping and Output Subroutine. This is dependent on the form of the computer programming.

The executive timing section may also be part of this subroutine.

6. COMPUTER PROGRAM BOOKKEEPING AND OUTPUTS

In addition to outputs calculated by the program, the output from the computer should summarize to a limited extent the input parameters. In particular, there should be provision for printing a descriptor for the case simulated as well as any appropriate remarks and, at the user's option, any of the other input data.

One of the user's options for output data will be a complete history of all major events that took place during the simulation. Major events include the birth and death of each module, the time and contents of each Tug flight, and the various waiting times of modules and launch vehicles within queues.

Among the other outputs available to the user, the following may be selected:

1. Availability of each satellite
2. Availability of each system of satellites
3. Number of flights to each satellite
4. Number of each type of module used
5. Number of times a module was requested when the pipeline was empty
6. Average time spent in pipeline by module
7. Number of Tug flights
8. Number of times a Tug was requested and not available
9. Average wait for Tug
10. Number of times the Shuttle was requested and not available
11. Average wait for Shuttle
12. Average waiting time between satellite outage and resupply of the satellite
13. Average utilization of Tug capacity
14. Number of times non-replaceable unit failed
15. Number of flights involving a priority satellite

16. Breakdown of total flights by orbit

17. Breakdown of total number of flights by Tug type

18. Average wait for launch of scheduled items

19. Standard deviation for above average values (from multiple runs)

20. Costs.

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